Name: Key

Chemistry 129.01 Spring 2012

General Chemistry

Midterm Examination:

Equations, constants and periodic table are provided.

You may use a calculator.

Show all your work!

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Bonus: _____/2

Total: _____/150

1. (24 pts.) Consider the reaction of 107 g of Fe_2O_3 with 85.8 g of CO to produce Fe and CO_2:

a) Balance the chemical equation for this reaction. (2 pts.)

$$\_\_\_\_ Fe_2O_3\,(s) + \_3\_ CO\,(g) \rightarrow \_2\_ Fe\,(s) + \_3\_ CO_2\,(g)$$

b) Determine the oxidation number of each element (in each reactant and product). Which element is reduced and which oxidized? Which are the oxidizing agent and reducing agent? (9 pts.)

Reactants		Products	
Element	Oxidation	Element	Oxidation Number
Fe	+3	Fe	0
O (in Fe_2O_3)	−2	C	+4
C	+2	O	−2
O (in CO)	−2		

Fe: +3 → 0 reduced Fe_2O_3 : oxidizing agent

C: +2 → +4 oxidized CO: reducing agent

c) Find the limiting reactant and the amount of Fe produced in **grams**. (10 pts.)

$$107\ g\ Fe_2O_3 \left(\frac{1\ mol\ Fe_2O_3}{159.70\ g\ Fe_2O_3}\right)\left(\frac{2\ mol\ Fe}{1\ mol\ Fe_2O_3}\right)\left(\frac{55.85\ g\ Fe}{1\ mol\ Fe}\right) = 74.8\ g\ Fe$$

$$85.8\ g\ CO \left(\frac{1\ mol\ CO}{28.01\ g\ CO}\right)\left(\frac{2\ mol\ Fe}{3\ mol\ CO}\right)\left(\frac{55.85\ g\ Fe}{1\ mol\ Fe}\right) = 114\ g\ Fe$$

Fe_2O_3 is limiting reagent.

Theoretical yield: 74.8 g Fe

d) If 15.3 g of Fe_3 are collected, what is the percent yield of the reaction? (3 pts.)

$$\%\ yield = \frac{Actual\ Yield}{Theo.\ Yield} \times 100 = \frac{15.3\ g\ Fe}{74.8\ g\ Fe} \times 100 = 20.5\%$$

(10 pts) Caffeine contains 49.5% C, 5.15% H, 28.9% N, and 16.5% O and has a molar mass of 195g/mol. Find its empirical and molecular formulas.

$$49.5\ g\ C \left(\frac{1\ mol\ C}{12.01\ g\ C}\right) = 4.12\ mol\ C$$

$$5.15\ g\ H \left(\frac{1\ mol\ H}{1.01\ g\ H}\right) = 5.10\ mol\ H$$

$$28.9\ g\ N \left(\frac{1\ mol\ N}{14.01\ g\ N}\right) = 2.06\ mol\ N$$

$$16.5\ g\ O \left(\frac{1\ mol\ O}{16.00\ g\ O}\right) = 1.03\ mol\ O$$

$$\frac{C_{4.12}}{1.03}\frac{H_{5.10}}{1.03}\frac{N_{2.06}}{1.03}\frac{O_{1.03}}{1.03}$$

$\Downarrow$

$C_4H_5N_2O$ ← Empirical Formula (97.11 g/mol)

$$n = \frac{195\ g/mol}{97.11\ g/mol} = 2$$

$$(C_4H_5N_2O) \times 2 = C_8H_{10}N_4O_2$$

← Molecular Formula

(8 pts.) Fill in the gaps in the following table. Each column may represent a neutral atom or an ion.

Symbol	$^{27}_{13}Al^{3+}$	$^{96}_{42}Mo$
Protons	13	42
Neutrons	14	54
Electrons	10	42
Mass Number	27	96
Charge	3+	0

4. (10 pts) The energy of an orbit in the hydrogen atom is:

$$E_n = -2.18\times10^{-18} J\left(\frac{1}{n^2}\right) \qquad where\, n = 1,2,3...$$

(a) For an electron transition in the hydrogen atom from n=2 to n=3, what is the associated change in energy? Does this transition correspond to absorption or emission of energy? (5 pts.)

$$\Delta E = -2.18\times10^{-18} J\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$= -2.18\times10^{-18} J\left(\frac{1}{3^2} - \frac{1}{2^2}\right) = 3.03\times10^{-19} J$$

$n = 2 \longrightarrow n = 3$ Absorption

(b) What is the wavelength of light this energy change corresponds to? What type of electromagnetic radiation is this? (5 pts.)

$$\Delta E = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{\Delta E} = \frac{(6.626\times10^{-34} J\cdot s)(3.00\times10^{8} m/s)}{3.03\times10^{-19} J} = 6.56\times10^{-7} m = 656 nm$$

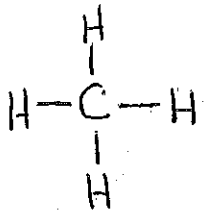
Visible Light

5. (8 pts.) Fill in the gaps in the following table.

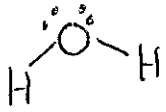
Name	Formula	Ionic or Covalent?
copper (II) sulfate	$CuSO_4$	ionic
dinitrogen tetroxide	N_2O_4	covalent
iron (III) chloride	$FeCl_3$	ionic
phosphorus trichloride	PCl_3	covalent

6. (5 pts.) Predict which of the following molecules would have bond angles of 105°, 107°, and 109.5°. Explain.

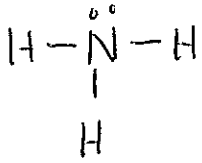
CH_4 , H_2O , NH_3



109.5°



105°



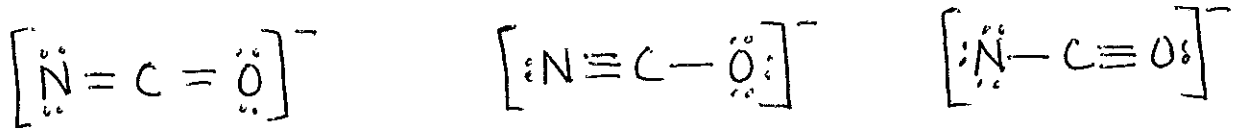
107°

They all have tetrahedral electron group geometries but the number of nonbonding groups and bonding groups are different. As the number of nonbonding increases, the bond angle decreases. A nonbonding group is more spread out in space and exerts greater repulsion.

7. (9 pts) The cyanate ion, NCO^-, has three possible Lewis structures.

(a) Draw these three Lewis structures, and assign formal charges to the atoms in each structure.

16 e⁻s



↑ ↑ ↑
-1 0 0

(1)

↑ ↑ ↑
0 0 -1

(2)

↑ ↑ ↑
-2 0 +1

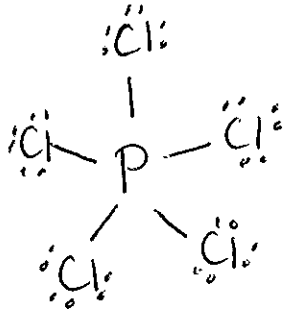
(3)

(b) What is the shape of the cyanate ion? Which Lewis structure is the preferred one? Why?

The cyanate ion is linear. Structures (1) and (2) have the smallest formal charges but structure (2) has the negative charge on the most electronegative atom. Structure (2) is the preferred one.

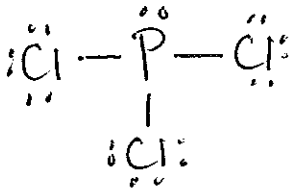
8. (12 pts.) Consider the following molecules: **PCl_5** , **PCl_3**. (i) Draw their Lewis structure, (ii) Determine the electron group and molecular geometries, (iii) Is the molecule polar or nonpolar?

(a) PCl_5 40 e⁻



Electron Group Geometry: trigonal bipyramidal
Molecular Geometry: trigonal bipyramidal
Polar or Nonpolar?: nonpolar

(b) PCl_3 26 e⁻



Electron Group Geometry: tetrahedral
Molecular Geometry: trigonal pyramidal
Polar or Nonpolar?: polar

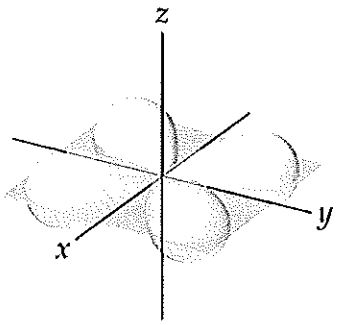
9. (6 pts) Using the periodic table as a reference, determine whether a bond between each of the following pairs of atoms is polar, nonpolar or ionic? Which is the most electronegative atom in each pair?

(a) N and F polar F is the most electronegative

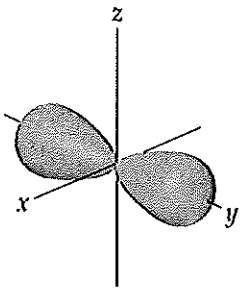
(b) O and O nonpolar

(c) Na and Cl ionic Cl is the most electronegative

10. (i) (8 pts) **Identify** each of the following orbitals, and give the **n and l values** and **the orbital designation** (e.i. 4f).



(in fourth shell)



(in fifth shell)

orbital: dxy
n= 4 l= 2
designation: 4d

orbital: p_y
n= 5 l= 1
designation: 5p

(ii) (2 pts) Tell whether the following combinations of quantum numbers are allowed or not allowed.

$n = 3,\ l = 3,\ m_l = -1$ — not allowed

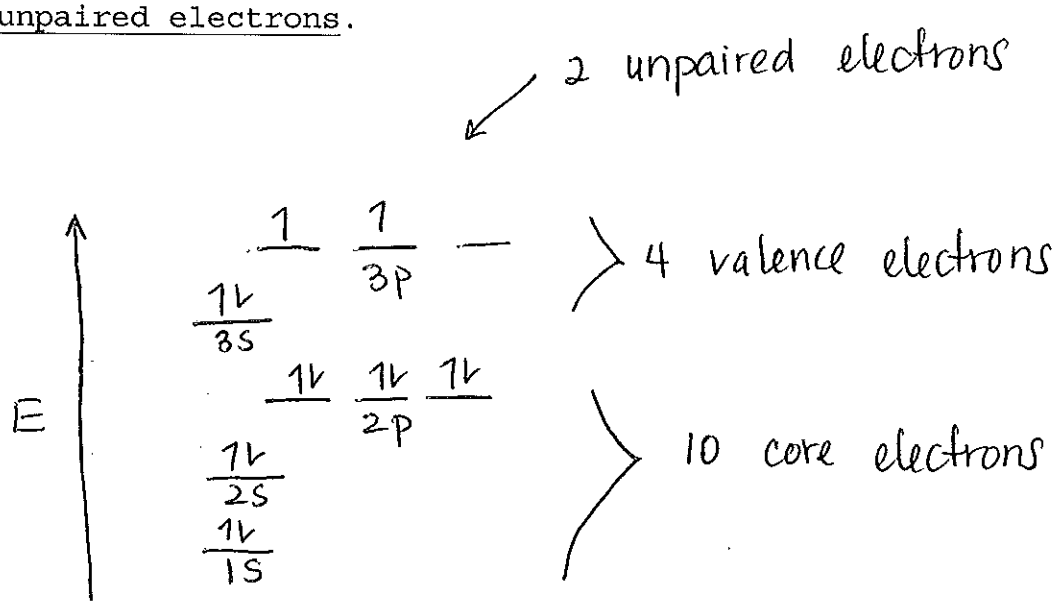
$n = 4,\ l = 2,\ m_s = 0$ — not allowed

(iii) (4 pts) What is the maximum number of electrons that can have of the following quantum numbers?

$n = 3,\ l = 2$ — 10 e^-s

$n = 4,\ l = 3,\ m_s = -½$ — 7 e^-s

11. (i) (6 pts) Draw the **orbital diagram** of the atom with ***atomic number 14*** and show the number of valence electrons, core electrons and unpaired electrons.



(ii) (2 pts) Write the **full** electron configuration for Br^-.

36 e^-s

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6$

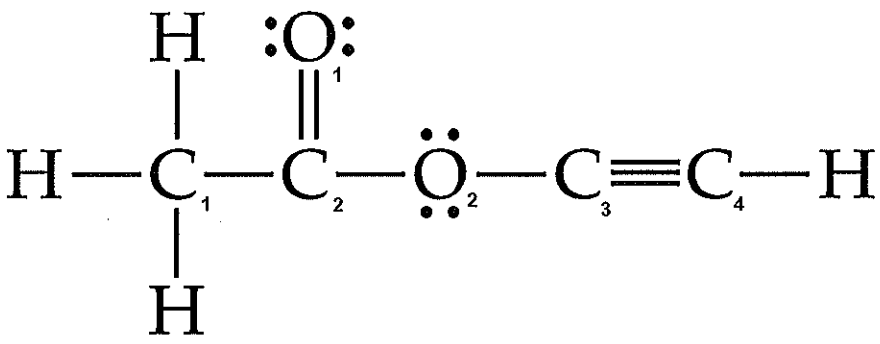
(iii) (3pts) Arrange the following elements in order of **increasing** atomic radius: Cs, Ga, O, Al, C, K.

$O < C < Al < Ga < K < Cs$

(iv) (3 pts) Arrange the following elements in order of **increasing** ionization energy: S, Rb, F, Ge, Ca.

$Rb < Ca < Ge < S < F$

12. (8 pts.) (a) What are the hybridizations of the **four carbon** atoms, the **two oxygen** atoms?



C_1: sp^3 O_1: sp^2

C_2: sp^2 O_2: sp^3

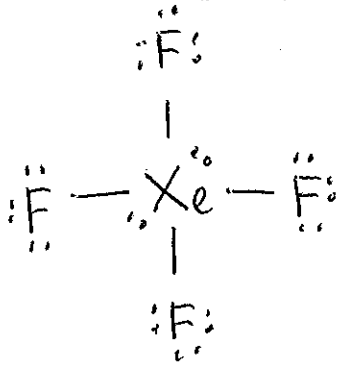
C_3: sp

C_4: sp

How many sigma bonds and pi bonds does the molecule have?

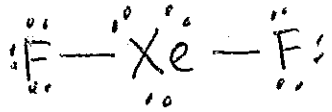
9 sigma bonds 3 pi bonds

(c) (6 pts.) Draw the Lewis structure of the following and determine the hybridization of the central atom: XeF_4 and XeF_2. How many sigma bonds and pi bonds do the molecules have?



sp^3d^2

4 σ bonds



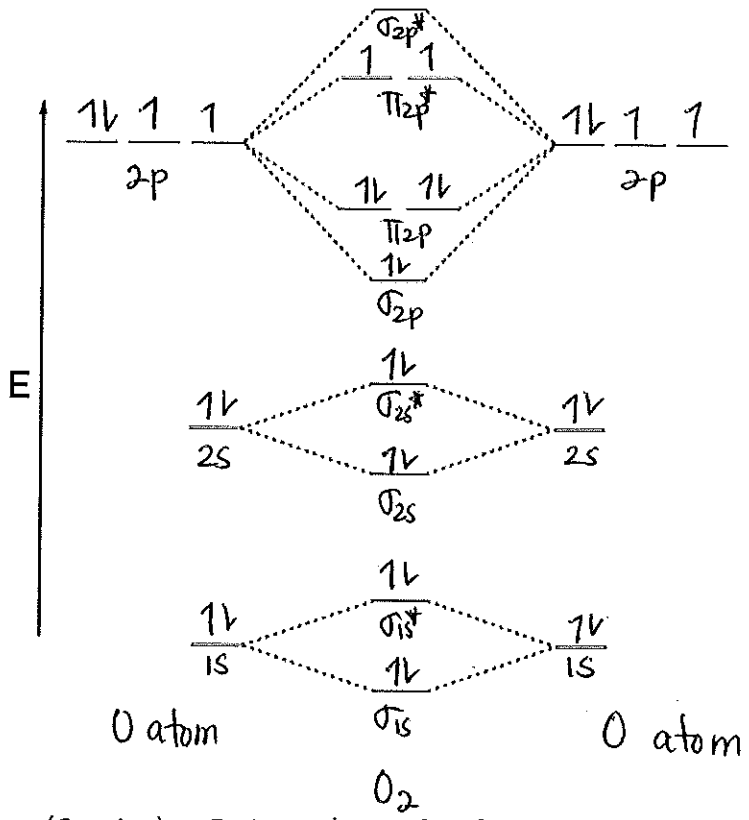
sp^3d

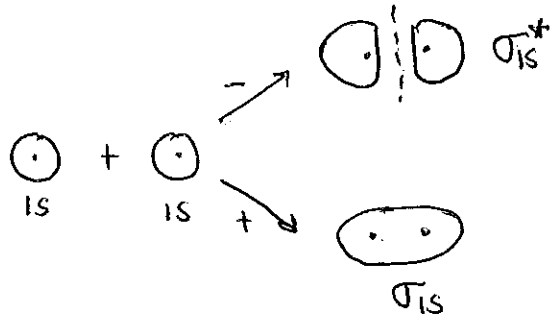
2 σ bonds

13. (17 pts.) Using the molecular orbital energy diagram given below (for **ALL** electrons):

a. (8 pts) Complete the molecular orbital energy-level diagram for O_2 and write its electron configuration. Label all the atomic orbitals and molecular orbitals. Sketch the shape of the σ_{1s} and σ_{1s}^* molecular orbitals.

$\sigma_{1s}^2\ \sigma_{1s}^{*2}\ \sigma_{2s}^2\ \sigma_{2s}^{*2}\ \sigma_{2p}^2\ \pi_{2p}^4\ \pi_{2p}^{*2}$





b. (3 pts) Determine the bond order of O_2. Is O_2 paramagnetic or diamagnetic? Why?

B.O. $= \frac{1}{2}$(# bonding e^- − # antibonding e^-) $= \frac{1}{2}(10-6) = 2$

O_2 is paramagnetic because it has 2 unpaired electrons.

c. (6 pts.) If two electrons are added from O_2 to form O_2^{2-}, how many unpaired electrons would O_2^{2-} have? Calculate the bond order of O_2^{2-}. Which would you expect to have a stronger bond, O_2 or O_2^{2-}? Longer bond? Why?

B.O. $= \frac{1}{2}(10-8) = 1$ O_2^{2-} has no unpaired electrons.

O_2 has a stronger bond because it has a higher bond order.

O_2^{2-} has a longer bond because it has a lower bond order.

Bonus: (2 pts)

Rank the following gases from least dense to most dense at 1 atm and 298K: Cl_2, SO_2 , N_2O. Explain.

$d = \frac{PM}{RT}$

Cl_2: 70.90 g/mol

SO_2: 64.06 g/mol

N_2O: 44.02 g/mol

$N_2O < SO_2 < Cl_2$ (density →)

The density of a gas is directly proportional to its molar mass.

Equations, Constants and Conversion Factors

$E = \frac{hc}{\lambda}$

$d = \frac{PM}{RT}$

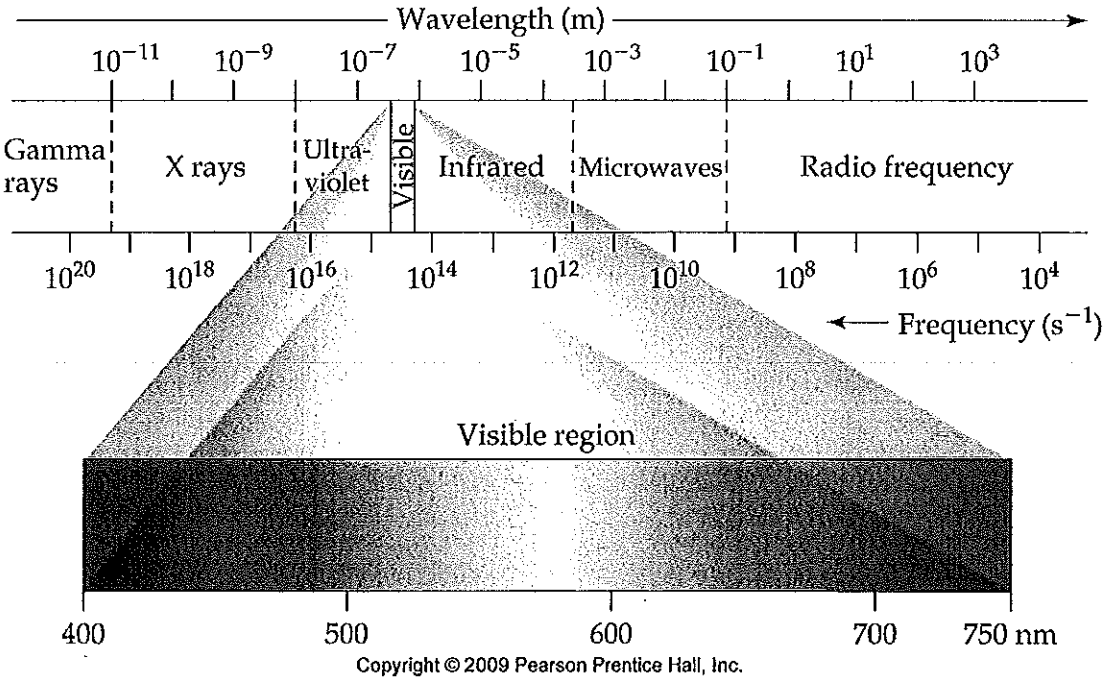
PV=nRT

1 nm = 10^{-9} m

h = 6.626 x 10^{-34} J.s

c = 3.00 x 10^{8} m/s

R = 0.0821 L.atm/(mol.K)



Periodic Table of the Elements

Chemistry Reference Sheet

California Standards Test

	1 1A												13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1	1 H Hydrogen 1.01	2 2A																2 He Helium 4.00
2	3 Li Lithium 6.94	4 Be Beryllium 9.01											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18
3	11 Na Sodium 22.99	12 Mg Magnesium 24.31	3 3B	4 4B	5 5B	6 6B	7 7B	8	9 8B	10	11 1B	12 2B	13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.07	17 Cl Chlorine 35.45	18 Ar Argon 39.95
4	19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.87	23 V Vanadium 50.94	24 Cr Chromium 52.00	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.39	31 Ga Gallium 69.72	32 Ge Germanium 72.61	33 As Arsenic 74.92	34 Se Selenium 78.96	35 Br Bromine 79.90	36 Kr Krypton 83.80
5	37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.60	53 I Iodine 126.90	54 Xe Xenon 131.29
6	55 Cs Cesium 132.91	56 Ba Barium 137.33	57 La Lanthanum 138.91	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
7	87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (269)	109 Mt Meitnerium (268)									

Key

11 — Atomic number
Na — Element symbol
Sodium — Element name
22.99 — Average atomic mass*

58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.97
90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

* If this number is in parentheses, then it refers to the atomic mass of the most stable isotope.